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HABITAT INFORMATION AND REHABILITATION ALTERNATIVES FOR RESTORING SPAWNING HABITAT OF WALLEYE AND SALMONIDS IN STREAMS

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ABSTRACT

This report provides a reference source for managers and scientists involved in rehabilitation of walleye and salmonid lotic habitats. We selected literature from primary journal articles and easily accessible "grey" literature. Streams within the Great Lakes watershed are emphasized. References are categorized by author, subject, and species indices. We present summary tables of physical characteristics of walleye and salmonid spawning habitat as well as the methods and results of previous rehabilitation projects.

RÉSUMÉ

Le présent rapport fournit une source bibliographique à l'intention des gestionnaires et des scientifiques travaillant à la remise en état d'habitats lotiques du doré et de salmonidés. Les textes ont été choisis à partir d'articles provenant des principales revues scientifiques ainsi que de documents non officiels qu'on peut se procurer facilement. L'accent est mis sur les cours d'eau faisant partie du bassin hydrographique des Grands Lacs. Les documents de référence sont classés par index des auteurs, des sujets et des espèces. Des tableaux récapitulatifs indiquent les caractéristiques physiques des sites de frai du doré et de salmonidés ainsi que les méthodes et les résultats de projets antérieurs de remise en état.

INTRODUCTION

This citation collection was compiled to serve as an initial reference source for managers and scientists involved in or planning rehabilitation of fisheries habitat in lotic ecosystems. In compliance with the objectives of the North Shore of Lake Superior Remedial Action Plans, for which this literature review was initiated, the references contained in this collection reflect an ecosystem approach to fisheries habitat restoration. Consequently, although lotic spawning habitat of walleye and Great Lakes salmonids have been emphasized, the information selection process includes habitat requirements of early life history stages in streams, processes affecting associated lotic habitats and a search for effects upon other ecosystem components.

The collected literature consists of both a habitat and a management component. References relevant to understanding critical lotic habitats of walleye, salmonids and northern pike have been included with results of studies intended to restore these habitats. Literature selections are mainly from primary literature but important and easily retrieved references from the "grey literature" are also included. Citations are meant to provide a cross-section of habitat information and restoration alternatives rather than an exhaustive compilation.

A numbered, alphabetical listing of references by author is accompanied by a subject index and an index to salmonid species. References were organized and formatted using the Bookends PC Reference Management System. A copy of citations in Ascci format is available by contacting:

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SELECTION OF REFERENCES

Our review was initiated using reference citations from Reeves and Roelofs (1982), Hall and Baker (1982) and Reiser and Bjornn (1979). The walleye-sauger bibliography by Ebbers et. al. (1988) was an invaluable source of walleye literature.

Selection of literature was guided by North Shore of Lake Superior Remedial Action Plans for riverine restoration. The diversity of these projects prohibited an extensive review of all subject areas. Instead, an informal selection criteria emphasized characteristics and rehabilitation of spawning and related fisheries habitats in lotic ecosystems. Target species included walleye, anadromous salmonids of the Great Lakes and salmonids resident in Great Lakes tributaries. This literature accounts for almost 2/3 of the compiled citations.

A less intensive search was conducted to accumulate references pertinent to other aspects of the plans. These projects encompassed island creation, shorelands restoration, marsh management, macrophyte introduction, pond creation and creation of spawning marshes for northern pike.

Efforts were directed at compiling at least the most widely cited material. Although references from both primary and grey literature are included, collection of information was influenced by accessibility. Accordingly, approximately 2/3 of the selections are from primary sources. Many potential references that were not immediately available have been excluded.

All citations, with assigned keywords, were entered on Bookends PC Reference Management System. Subject indexes were developed with the aid of computerized keyword searches. Selected physical characteristics of walleye and salmonid spawning habitat were summarized in tables from relevant references. Table categories consist of geographic location, spawning period, temperature, site area, substrate size, current velocity, water depth, site description and study objectives. Salmonid tables also incorporate redd characteristics. All quantified values were converted to standardized metric units, where possible. Table categories that tended to be reported variably, such as substrate size, were recorded unaltered. Qualitative information

augmenting interpretation or comparison of table entries was also included.

Other tables were created to summarize studies evaluating or documenting spawning habitat restoration. Restoration strategies were classified into several general approaches to spawning habitat rehabilitation, including addition of substrate, substrate stabilization and recruitment, gravel cleaning, construction of spawning channels and management of spawning marshes. Table categories describe study objectives, site descriptions, methods of restoration and results. An additional column accommodates general evaluations of rehabilitation strategies.

GENERAL DISCUSSION

The tables in Appendix 1 contain information from 26 separate sources reporting walleye and salmonid spawning habitat and spawning periods. Appendix 2 details restoration alternatives for rehabilitation of spawning habitat from 29 references. Literature sources differed between Appendix 1 and 2. The proportions of primary and "grey" literature in Appendix 1 tended to be representative of the entire citation collection, with the exception of the walleye literature. Approximately 70% and 30% of the summarized salmonid references are from primary and "grey" literature, respectively. Only 38% of the walleye citations, however, are from primary sources. In contrast to the general pattern in Appendix 1, "grey" literature composed almost 80% of the restoration citations in Appendix 2.

Valuable data was available from both primary and "grey" reference sources. Much of the "grey" literature, however, was difficult to obtain and the quality and consistency of reporting was less than in the primary literature. In Appendix 1, spawning periods and temperatures were usually regularly available while substrate types, water depths and current velocities were reported less constantly. Comparisons of substrates are somewhat confounded by the variability of methods for measurement and evaluation, particularly in the salmonid literature. The walleye literature often lacked quantitative substrate measurements entirely. In Appendix 2, evaluations of restoration projects were often unsatisfactory, generally only short-term and occasionally were not reported at all.

Spawning walleye apparently require movement of water either by currents in rivers or marshes or wind-generated waves along shorelines (Eschmeyer 1950; Priegel 1970; Busch et. al. 1975; Colby et. al. 1979). Spawning areas in rivers tend to be in backwater or border habitats (Corbett and Powells 1986; Paragamian 1989; Pitlo 1989) often in the vicinity of dams blocking further upstream migration (Eschmeyer 1950; Fraser 1954; Gibson and Hughes 1977; Maraldo 1986; Paragamian 1989; Pitlo 1989)

The most constant feature of natural brook trout spawning habitat is the presence of upwelling, regardless of substrate or current attributes. Carline and Brynildson (1977) and Carline (1980) report the occurrence of brook trout redds in pure sand in areas of upwelling and in spring-fed ponds. Both temperature and hydraulic conditions of upwellings appear to be significant factors influencing choice of redd sites. Temperatures at peak spawning of 6cC correspond to temperatures of upwelling water in the studies examined (Carline 1980; Witzel and MacCrimmon 1983). The cooler water temperatures of Webster's (1962) upwelling spawning facilities may have contributed to the failure of some of these restoration attempts to attract brook trout.

Brown trout have similar spawning periods and habitat preferences as brook trout but upwelling is not a criteria for habitat selection (Hansen 1975; Witzel and MacCrimmon 1983). Both species tend to spawn in smaller substrate sizes than the larger salmonids.

Spawning habitat of rainbow, coho, chinook and pink salmon is more difficult to differentiate based upon the reviewed literature. Ranges of values for these species tend to be very similar. Results of one study suggest that spawning strategies of some species may be separated by the area of a river system utilized for redd construction. Carl (1982) found evidence of preferential spawning by chinook salmon in main stem streams and by coho in tributaries.

Most spawning habitat restoration has been directed at anadromous salmonids. Rehabilitation of walleye spawning habitat was mostly confined to addition of substrate. Other restoration alternatives ranged from low-cost, easily implemented methods, such as

use of a fire hose to clean spawning gravel, to expensive, engineering-intensive projects like construction of spawning channels. Impacts of restoration on spawning, egg survival and recruitment, where reported, were variable. The success or failure of a project was generally site-specific and often poorly evaluated.

SUBJECT INDEX

CRITICAL HABITATS: Spawning, incubation and nursery habitats including environmental requirements of spawning adults, eggs and larva, factors affecting reproductive success and spawning and larva behaviours.

SALMONIDS

SPAWNING HABITAT

10 13 14 15 19 28 31
32 37 46 63 64 66 102
109 112 155 156 157 168 182
183 194 200 207 213 216 219
220 222 232 234 237 247 248
252 253 258 270 275 284 287
293 302 304

INCUBATION HABITAT

10 44 49 58 62 66 95
109 129 129 182 185 207 214
221 232 233 234 247 248 250
252 255 257 260 270 274 278
287 300 303 305

REARING HABITAT

26 27 34 66 71 80 88
109 113 117 121 149 158 159
175 181 192 207 211 212 220
232 236 239 241 249 251 254
271 276

WALLEYE

SPAWNING HABITAT

8 11 33 47 50 53 55
60 61 65 68 72 76 77
85 87 88 93 116 135 136
137 173 177 197 199 201 204
215 224 227 230 237 242 298

INCUBATION AND LARVAL HABITATS

4 9 11 33 50 51 53
68 77 93 122 123 127 128
129 133 134 135 151 152 171
197 202 206 223 298

NORTHERN PIKE

SPAWNING, INCUBATION AND LARVAL HABITATS

61 81 88 119 120 167 201
224 282

REHABILITATION OF CRITICAL HABITATS: Restoration, enhancement or creation of critical habitats, evaluation of effectiveness and description of techniques.

SPAWNING HABITAT

SALMONIDS

6 29 38 39 41 54 66
88 91 100 101 107 114 124
146 147 148 163 174 184 186
187 188 203 205 209 231 238
272 277 292 297

WALLEYE

7 68 84 93 106 135 169
173 180 195 228 262 273

REARING HABITAT

SALMONIDS

6 23 27 43 66 88 100
101 107 114 124 146 148 187
189 190 203 231 254 277 279
291 297

HABITAT MANAGEMENT

STREAMS

RIPARIAN HABITAT: Interactions of riparian and stream ecosystems, including riparian management.

12 45 100 110 111 140 175
192 217 231 232 235 266 295
297

WOODY DEBRIS: Role and management of woody debris in streams and its function as fisheries habitat.

17 20 21 27 71 161 162
175 179 192

SEDIMENTATION: Sedimentation, effects of sedimentation and sediment control in stream ecosystems.

1 2 3 17 18 32 103
104 117 161 185 191 216 220
248 283

STREAMBED HYDRAULICS: Dynamics of interchange of stream and intragravel water including methods for measurement of the intragravel environment.

95 97 118 221 250 252 270
278 287

MEASUREMENT OF SUBSTRATE SEDIMENTS: Methods for sampling and evaluating streambed substrates.

44	79	165	182	217	218	219
226	259	268	274	289	290	294

STREAM IMPROVEMENT STRUCTURES: Description and evaluation of structures for the improvement of fish habitat in streams.

6	23	24	28	30	40	69
70	73	88	90	91	99	100
101	108	114	124	125	130	131
132	146	147	148	178	193	231
240	277	291	292	296	297	

HABITAT ASSESSMENT: Models of stream habitat or habitat quality assessment.

22	25	83	139	141	217	246
263	264	265	286			

WETLANDS

ESTUARIES AND COASTAL MARSHES: Fisheries habitat in estuaries and coastal marshes and estuarine restoration.

48	52	75	107	142	143	159
170	254	256	267	279		

PONDS AND BACKWATERS: Role of backwaters and riverine ponds as rearing and nursery habitats for fish.

34	43	107	114	120	211	212
236	249	271	301			

MARSH MANAGEMENT: Wetlands restoration or creation and marsh management for fish and waterfowl, including relationships between aquatic vegetation and waterfowl, invertebrates or fish.

5	42	57	67	74	78	81
86	92	115	120	138	144	145
150	154	167	210	256	261	288
299						

AQUATIC VEGETATION: Macrophyte community dynamics and establishment of aquatic vegetation.

59	98	143	142	150	196	210
245	256	280	281	285		

INVERTEBRATES: Invertebrate habitat associations or effects of habitat alteration on invertebrate communities in streams or wetlands.

11	16	30	39	57	71	78
89	92	94	110	138	154	178
184	191	217	237	279	288	

SHORELANDS

SHORELINE DEVELOPMENT: Effects of shoreline development and management for flood and erosion control.

74 82 105 140 141 153
170208 229 244

ARTIFICIAL REEFS AND ISLANDS: Description of artificial nearshore structures and evaluation of their effects on the fish community and coastal environment.

36 88 89 96 126 164 166
176 198 209 225 [illegible]3 269 272
279 280 281

SALMONID SPECIES INDEX

Salvelinus fontinalis

2 3 12 15 24 25 30
35 38 39 56 58 73 90
178 240 258 292 293 295 296
297 301 304 305

Salmo trutta

2 10 12 15 24 25 35
56 58 73 90 102 108 112
113 125 160 168 178 232 253
258 295 296 297 304 305

Salmo gairdneri

12 15 19 23 24 25 27
32 34 35 45 49 54 58
63 64 73 80 88 90 124
125 129 147 148 149 158 160
168 178 192 200 207 214 216
219 220 232 233 251 255 257
258 260 271 275 291 295 296
297 302 303

Onchorhynchus kisutch

15 27 28 31 32 34 37
43 45 62 109 121 124 147
149 168 175 181 190 192 211
212 214 232 234 241 247 251
255 258 271 276 284 291

Onchorhynchus tshawytscha

15 26 28 31 37 41 46
58 80 101 117 157 159 194
216 219 220 222 232 233 236
254 257 258 271 276

Onchorhynchus gorbuscha

15 27 146 147 155 156 159
182 183 185 232

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APPENDIX 1

SPAWNING PERIOD AND SPAWNING HABITAT CHARACTERISTICS OF WALLEYE AND GREAT LAKES SALMONIDS IN STREAMS

WALLEYE

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (°C)	Site Area	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
Manitoba	S:May 19 E:May 25 P:---	6°C	---	---	---	---	-reports on the cessation of walleye spawning in 2 tributaries of Heming L., Manitoba, after a sudden temperature decline	60
Michigan	S: Apr 22- May 6 E: May 19- early Jun P: May 1- 18 (lake) Apr 12- 14(stream)	Start of spawning: 1- 4°C (lake) At peak spawning: 7- 10°C (lake) 4- 7°C (stream)	16 km (lake) 25 km (stream)	Lakeshore: -mixture of gravel, rubble and boulders, with a substratum of sand and fine gravel -also used areas with fine gravel Stream: -boulders, rubble, gravel	< 0.90 (lake) 1.5- 2.4 (stream)	"moderately fast"	-studied life history of walleye in L. Gogebic, Michigan and the Muskegon R. spawning population -spawning in the lake concentrated along wave-swept shoreline exposed to prevailing winds -stream spawning concentrated within 0.8 km below a dam blocking further upstream migration -stream width at spawning site approx. 75 m with a stony bottom	77
Ontario	S:Mar 15 E:Apr 30 P:Apr 1- Apr 5	6- 11°C	67.5 m long	Lake spawning: -gravel pockets interspersed among boulders and broken rock	---	---	-investigated walleye spawning & upstream migration in Consecon Lake and its main inflow - over 90% of spawning stream consisted of flooded swampland with a bottom of grass, organic debris and muck - creek dry after spring run-off - spawning occurred below dam 112.5 m upstream from Consecon Lake and along 50% of the lakeshore	87
Northern Saskatchewan	S:Apr 17- May 6 E:May 8- May 25 P:Apr 30- May 21 Duration of Peak: 5- 7 days (6 years of observations)	3- 11°C	---	---	---	---	-studied growth and ecology of walleye in Lac La Ronge, Saskatchewan, with particular emphasis on spawning and movements - spawning examined over time period of 6 years in the largest lake inlet, the Montreal river and a second tributary, Potato River	230

WALLEYE

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (°C)	Site Area	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
Wisconsin	S:mid April E:May 1 P:---	Start of spawning: 3- 7°C At peak spawning: 9- 10°C.	---	- eggs deposited on gravel substrate or broken rocks on wind-swept, rocky shorelines in lakes and inlets -spawning may also occur on sand or flooded marsh vegetation	0.60- 1.20	---	- discusses life history, ecology and management of walleye in Wisconsin	197
Utah	---	7- 12°C (lake) 7- 10°C (stream)	---	Lakeshore: -spawn along rocky, gravelly areas around islands and along shores exposed to prevailing winds Stream: -large gravel and rubble -pools used as resting areas during the day	0.9- 1.5 (lake) 0.15- 1.2 (stream)	---	-examined factors affecting failure of walleye fry stocking in Utah Lake, a shallow, eutrophic waterbody, covering 310.8 km^2 and with a maximum depth of 3.9 m -majority of lake water supplied by spring sources and a major tributary, the Provo River	8
North-Central Minnesota	---	5- 18°C (incubation temper-atures)	92.9 m^2- 139.4 m^2	-avg. egg survival of 2.4% on soft muck-detritus bottom, 8.6% on firm sand bottom and 25% egg survival on gravel-rubble bottoms with 2.5 to 15.0 cm dia. substrates	0.3- 0.75	---	- study investigates spawning site selection by walleye and spawning success on several bottom types in a series of lakes comprising most of a Mississippi R. headwater reservoir - egg survival was highest on gravel-rubble bottom, intermediate on firm sand and lowest on soft muck detritus substrate	135
Western Lake Erie	S:Mar 31- Apr 19 (usu. 2nd wk of Apr) E:--- P:3rd wk of Apr	Start of Spawning: 4- 6°C At peak spawning: 8°C	---	- reef spawning over boulders, cobbles and pebbles underlain by bedrock.	<4.50	---	- conducted 10 year walleye spawning habitat survey in western Lake Erie to locate areas of egg deposition, determine egg survival, and to evaluate the relationship between environmental variables and year class abundance - year class strength found to be inversely proportional to incubation time, as influenced by water temperature	11

WALLEYE

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (°C)	Site Area	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
Wisconsin	S:Mar 30- Apr 20 E:Apr 25- May 4 P:April Duration: 5- 23 days	Range: 2- 16 °C At peak spawning: 6- 8 °C	23.2 ha- 950.8 ha	Preferred: -mats of flooded vegetation adjacent to tributaries of Lake Winnebago. -rubble and gravel along lakeshore and around islands & reefs During Low Water Levels: -sand, rubble and gravel below a dam. -sand bars in main river channel.	0.30- 0.75	- inlet & outlet of spawning marshes provides continuous water flow during high water levels in spring.	- study examines spawning requirements of Lake Winnebago walleye, factors affecting egg and fry development and determines variables limiting juvenile survival - most spawning in flooded marsh areas adjacent to tributaries of Lake Winnebago, the Fox and Wolf Rivers	223
Western Lake Erie	Hatchery records: S:2nd or 3rd wk of Apr Observed: S:Apr 8 E:Apr 23 P:Apr 15	Range: 5.6- 10.0 °C At peak spawning: 7.2 °C	---	---	---	---	- studied Lake Erie 1959 walleye year class to gain further understanding of the species' life history and population dynamics - spawning in open waters of western Lake Erie	206
Western Lake Erie	S:Mar 31 (earliest) E:Apr 19 (latest) P:---	Start of spawning: 2.2- 5.5 °C	51.3- 110.4 ha available for spawning depending on water levels.	- most spawning over bedrock reefs and around island archipelagoes.	<3.6	- spawning shoals susceptible to wind-caused currents	- examined relationship between various environmental factors and year-class strength of walleye in western Lake Erie	33
Northern Wisconsin	S:Apr 21- May 5 E:--- P:--- (4 years of observations) Duration: 1- 3 days	Approx. 7- 15 °C	< 3 m diameter per shoal	- approx. 0.63 cm to 5.0 cm diameter particle size (natural shoals)	0.3- 0.6	---	- assessed use of artificial reefs by spawning walleye in a 241 acre soft-water lake characterized by a predominantly sand and muck shoreline - small, natural gravel shoals along lakeshore also investigated - details of artificial reef assessment given in Appendix 2	180

WALLEYE

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (oC)	Site Area	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
Eastern Ontario	---	---	---	---	---	Mean: 120 Range: 77- 187 (position of measurement not recorded)	- propsed criteria for the construction of an artificial stream-side spawning channel for walleye - velocity measurements determined by author over well-known walleye stream spawning beds in eastern Ontario	228
Manitoba	S:Apr 24 E:--- P:May 1- 4	Range: 5- 14°C At peak spawning: 9- 14°C	503 m long	- highest egg counts on gravel and cobble substrates (0.63 to 7.5 cm) -sand and rock also used	Mean: 0.33- 0.48 Range: 0.04- 1.13 (Over cobble and gravel substrates)	Mean: 21.3- 49.2 Range: 14.1- 130.8 (Over cobble and gravel substrates)	- investigated substrate selection by stream spawning walleye, spawning success and fry migration - study area consisted of an intermitent tributary of Falcon Lake, Manitoba - small water fall blocked walleye passage at upstream end which was characterized by riffles and pools - downstream section meandering with deeper, slower water - artificial spawning beds & cover also constructed and investigated (see Appendix 2)	93
---	S:Jan- Feb (earliest) E:June (latest) P:--- Duration: 4- 34 days Duration of Peak: 1- 10 days	5.6- 11.1°C	may be <1 m diameter	- generally, a variety of substrate types in lakes or streams where current or wave-action and sediment characteristics permit a sufficient oxygen supply to eggs.	values reported range from 0.10- 4.57	---	- presents a synopsis of biological data on walleye	50
Western Lake Erie	---	---	---	- bedrock reefs (dolomite and limestone) and associated rock rubble and gravel ranging from small pebbles to boulders up to 1.5 m diameter. - abundant solution cavities up to 1 to 2 cm in diameter	---	Avg over 10 yr period: 7.7 (bottom) 14.4 (surface) max: 50	- presents information on natural walleye spawning reefs in Lake Erie for use in planning artificial reefs	116

WALLEYE

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (°C)	Site Area	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
Southeastern Ontario	S:Apr 16 E:Apr 23 P:Apr 18 and 19	Range: 4- 16.4°C At peak spawning: 4.0- 12.0°C	Approx. 15- 30 m long	-egg survival of 31- 65% on gravel-rock (enhanced and natural sites); 1- 50% on sand; and 0- 14% egg survival on mud-detritus	1- 2	---	- investigated spawning interactions of walleye and white sucker at 2 inlets of a southeastern Ontario lake - walleye spawning concentrated in border and backwater habitats surrounding a riffle below a culvert that blocks further upstream migration - stream width 5-7 m	53
South Central Ontario	S:Apr 4 E:Apr 21 P:Apr 16	Range: 4.3- 9.9°C At peak spawning 6.5°C	144 m long	-boulders, rocks	---	---	- examined effects of water level fluctuations on walleye reproductive success at Lock 19, Peterborough - spawning tributary managed by Trent-Severn waterway for navigation & flood control - spawning occure for a distance of 144m below dam and 32 km upstream of Rice Lake - mean channel width 58.4 m - spawning area bounded by training wall on one side of channel and a sloping bank of boulder and rock on the other - walleye spawn approx. 2 to 2.5 m from shore	173
Eastern Ontario	Estimated time of spawning: April 8- 13	---	---	- most confirmed spawning sites with rock-rubble substrate - gravel-rock, silt-detritus, sand-gravel, and sand areas also used.	---	---	- investigated spawning activity of walleye and muskellunge on 11 walleye lakes and 9 muskellunge lakes in Bancroft District, Ontario Ministry of Natural Resources	65

WALLEYE

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (oC)	Site Area	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
Iowa	S:April 1 E:Apr 7	5.0- 12.0°C	---	-large cobble with diameters from 1.3- 25.4 cm	0.6- 1.2	60- 150 (at 2/3 of water depth)	- identified seasonal habitat preferences of walleye in the Cedar River system, Iowa, identified walleye spawning sites and examined movements - most spawning in vicinity of a tailwater riffle below a dam - spawning tributary characterized by well-developed riffle-pool transitions, gravel and cobble substrates, pools up to 3.7 m deep and presence of woody structure	204
Iowa	S:Mar 28 E:May 5 P:April Duration: 11- 27 days	Range: 5- 15°C At peak spawning: 8.3- 12.2°C	800- 1600 m long	-mixture of relatively large gravel, cobbles and some boulders in a hard sand/clay matrix. -predominantly small gravel with some sand	0.6- 6.1	43- 116 (13 cm above substrate)	- identified walleye spawning habitat in an area extending 12 km downstream from one of a series of locks and dams facilitating commercial navigation in the upper Mississipi R. - spawning areas located at distances of 3 to 7 km below dam in main channel border habitats and on outside portions of river bends where thalweg meets dominant landforms - extensive proximal backwater area present	215

BROOK TROUT

Where	Spawning Start/ End /Peak (S / E / P)	Spawning Temperature (oC)	Redd Area (m^2)	Egg Depth (cm)	Substrates	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
Oregon	---	---	---	---	---	0.09	1- 23	-develops spawning velocity and depth criteria for Oregon salmonids	258
Wisconsin	S:mid Oct E:Jan 9 P:early Nov	6 ^{o}C in areas of upwelling	---	7- 15	- sand and gravel substrate <2.5 cm diameter, in areas of upwelling groundwater - several redds constructed in pure, coarse sand	---	---	- describes effects of hydraulic dredging on physical and chemical characteristics of spring ponds with particular reference to brook trout populations - most study ponds situated at headwaters of trout streams in remote locations - pond area ranged from 0.36 to 2.51 ha with mean and maximum depths from 0.64 to 1.68 m and 1.68 to 5.18 m, respectively.	39
Wisconsin	---	---	---	---	-substrates had a fine particle content (<0.2 cm diameter) of 0.8- 76.5%, with a mean fine content of 45%	---	Avg: 0.007 Range: 0.003- 0.012 (velocity of groundwater seepage)	- describes attempts to augment brook trout spawning sites in two of the spring-fed kettle ponds studied by Carline & Brynildson 1977 - spawning in both natural and rehabilitated sites reported.	38
Southwestern Ontario	S:Oct.1 E:Nov.25 P:--- Duration:3-5 wks	Range: 3- 13 ^{o}C At peak spawning: 6- 8 ^{o}C	---	---	geometric mean particle diameter: 0.57 cm	Mean: 0.24 Range: 0.07- 0.65	Mean: 17.6 Range: 3.0- 42.0 (10 cm above substrate)	- study and stream characteristics described for brown trout - brook trout spawned exclusively in areas of groundwater seepage - flows used by brook trout for spawning did not exceed 177 l/s.	304

BROWN TROUT

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (oC)	Redd Area (m^2)	Egg Depth (cm)	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
Oregon	---	---	---	---	---	$\geq$ 0.24	21- 69	-develops spawning velocity and depth criteria for Oregon salmonids	258
Michigan (lower Peninsula)	S:Oct.15 E:Nov.10 P:---	Mean Temp during spawning period: 5.2- 9.1^{o}C (3 years of measurements)	---	---	-gravel	---	---	- investigated role of groundwater on spawning of brown and brook trout in Poplar Creek, Michigan - study stream characterized by a mean discharge of 0.54 m^3/s, stable flow and predominantly groundwater inflow with little overland flow - substrates in 0.8 km study area comprised of 31% gravel, 22% sand and the remainder mostly sand containing wood, cobble, detritus and resistant clay outcrop - no preference by spawning brown trout for sites with or without groundwater	102
Western N.Am.	---	---	0.5	---	-particle sizes of 0.64- 7.62 cm	$\geq$0.09	14- 91	-details habitat requirements of anadromous salmonids	232
Wisconsin	S:late Oct E:Jan P:Nov- mid-Oct	---	---	---	-particles <1.0 mm and <0.25 mm accounted for an average of approx. 24% and 4% of redd substrates, respectively	0.11- 0.45	15.6- 75.0	-study implemented to determine effects of impoundment in Trout Creek on spawning habitat and embryo survival of brown trout -study stream characterized by a base flow of 0.22 m^3/s, an average width of 2.16 m and a gradient of 10.3 m/km	10
Lake Erie Tributary	S:Nov.4 E:Nov.5 P:---	7^{o}C	---	---	-64.1% gravel & stones -35.9% sand ($\leq$ 2 mm dia)	---	Mean: 36	- data based on 1 pair of spawners - report and study stream described for rainbow trout	168

BROWN TROUT

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (oC)	Redd Area (m^2)	Egg Depth (cm)	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
New Zealand	---	---	---	---	-mean particle size of 1.4 cm, with a range of 0.5- 2.8 cm	Mean: 0.31 Range: 0.06-0.82	Mean: 39.4 Range: 15- 75 (2 cm above highest point of redd or at snout position of spawner)	- quantified environmental variables of microhabitats used by brown trout for feeding and spawning in rivers - study area comprised of 2 tributaries and 4 main stem river systems - stream characteristics ranged from 1-350 m^3/s mean annual flow, an average width of 10-40 m, and gradients of 0.25 to 0.56% - channel character included straight, meandering and braided	253
Southwestern Ontario	S:Oct.8 E:Nov.19 P:--- Duration:2-4 wks	Range: 3- 13°C At peak spawning: 6- 8°C	---	---	-geometric mean particle size: 0.69 cm	Mean: 0.26 Range: 0.07- 0.58	Mean: 46.5 Range: 10.8- 80.2 (10cm above redd surface)	- documented environmental variables affecting redd site selection by brook and brown trout in 6 streams within 4 southwestern Ontario agricultural watersheds - stream characteristics reported included gradients from 2.91 to 23.19 m/km and stream flows from 21 to 600 l/s - brown trout typically spawned in flows up to 600 l/s without preference for areas with upwelling groundwater	304

RAINBOW TROUT

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (°C)	Redd Area (m^2)	Egg Depth (cm)	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
Idaho	S: late Mar E: early Jul P: Apr 20- May 10	At peak spawning: 2- 8°C	Avg: 5.46 Range: 2.1- 11.3	---	-70% of substrate with particle size of 1.25- 10.0 cm	0.21 (minimum)	avg: 69- 75 (12 cm above streambed)	-studied steelhead spawning behaviour and redd construction in Clearwater and Salmon River systems	200
Lake Huron Tributary	Winter Run: S:Dec 29 E:Feb 14 P:Jan 15- Feb.5 Spring Run: S:Feb 20 E:Apr 30 P:Mar 16- Apr.16 (1970)	Range for both runs: 0.3- 10°C At peak spawning: 6- 8°C (spring run only) (1971)	---	---	-gravel diameter in riffles: mode: 2- 5 cm range: 2- 30 cm (1971)	---	---	- documents migration and extended spawning of rainbow trout in Bothwell Creek, a tributary of Lake Huron -stream length of 42 km, including tributaries, avg. gradient of 6.5 m/km, minimum flow of 0.14 m^3 from spring sources and maximum freshet of 5.7 m^3 - some silting evident - numerous gravel riffles	63, 64
Oregon	---	---	---	---	---	0.24	40- 91	- develops spawning velocity and depth criteria for Oregon salmonids	258
Western North America	---	Steelhead: 3.9- 9.4°C Rainbow: 2.2- 20.0°C	Steelhead 4.4- 5.4 Rainbow: 0.2 (average redd areas)	---	Steelhead: 0.6- 10.2 cm Rainbow: 0.6- 5.2 cm	Steelhead: 0.12- 0.70 Rainbow: 0.09- 0.90	Steelhead: 23- 117 Rainbow: 21- 91	-details habitat requirements of anadromous salmonids	232
Lake Erie Tributary	S:Nov 9, Jan 24, Apr 5 E:May 14 P:Apr 9- May 14	At start of spawning: 1°C- 9°C At peak spawning: 5- 15°C	---	---	-65.3% gravel and stones -34.7% sand ≤ 2 mm dia.	---	Mean: 38	- study reports on spawning runs in relation to environmental variables of rainbow trout, brown trout and coho salmon - study area consisted of a 902 m stream section from mouth of Normandale creek, a Lake Erie tributary, to a culvert 48 m below a dam blocking further upstream fish passage - substantial deposits of sand and silt on stream bottom	168

RAINBOW TROUT

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (°C)	Redd Area (m^2)	Egg Depth (cm)	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
Pacific Northwest	Winter run: Dec- Feb (hatchery) late Mar- early May (wild) Summer run: spring	Range: 3.9- 9.4°C	5.5	7- 30	-1.0 to 11.4 cm dia. gravel	≥0.24	76.2	- describes life history and environmental requirements of steelhead trout - spawn in cool, clear, well-oxygenated streams	207
New Zealand	S:early Apr E:mid Oct P:---	Mean monthly water temperature from May to December: 6.9- 11.9°C	---	---	- coarse and intermediate substrates favoured (geometric mean particle size: 23.8 and 5.7 mm) in areas at heads of riffles or in runs where bed sloped upstream - fine substrate also used (geometric mean particle size 3.5 mm)	---	---	- examined effects of interference competition on spawning success of brown and rainbow trout - study area consisted of a main spawning tributary of Lake Alexandria - stream length 2.4 km, meandering, with well-defined banks, mean gradient of 1.3% and mean discharge of 0.125 m^3/s - habitat composed of riffle/run sequences interspersed with pools - streambed consists of mud, sand and rounded gravel and stones - spawning over approx. 940 m of stream length	112

COHO SALMON

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (°C)	Redd Area (m^2)	Egg Depth (cm)	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
Columbia River	S:--- E:--- P:Oct.22	Range: 6°C- 14°C	Avg: 2.86	Avg: 20.0 Range: 7.5- 50	-10% >15.0 cm -85% ≤15.0 cm -5% mud/silt/sand	Avg: 0.20 Range: 0.05- 0.65	---	- determines stream area required by spawning Pacific salmon pairs in Columbia R. tributaries. - coho showed a preference for small streams with a flow of 0.09 to 0.12 m^3/s - versatile redd-building exhibited with nests located on flat slate-shale rubble bottoms, around embedded rubble bottoms, around embedded boulders and fallen trees, and in areas with up to 10% mud	31
Oregon	---	---	---	---	---	0.15 (minimum)	21- 70	-develops spawning velocity and depth criteria for Oregon salmonids	258
Western USA	---	Range: 4.4- 9.4°C	Avg:2.8	---	-particle sizes from 1.3- 10.2 cm dia.	≥ 0.15- 0.38	14- 93	-details habitat requirements of anadromous salmonids	232
Lake Erie Tributary	S:Nov 2- Nov 9 E:Dec 19 P:---	Minimum: 1°C At peak spawning: 4- 9°C	---	---	-65.3% gravel & stones -34.7% sand ≤ 2 mm dia.	---	Mean:38	- study reports on spawning runs in relation to environmental variables of rainbow trout, brown trout and coho salmon - study area consisted of a 902 m stream section from mouth of Normandale creek, a Lake Erie tributary to a culvert 48 m below a dam blocking further upstream fish passage - substantial deposits of sand and silt on stream bottom	168
Washington	---	---	---	Avg.:13.7	- smooth, rounded gravel	---	---	- measured relationship between nest depth and female size in a spawning tributary of Deer Creek, Washington	284

COHO SALMON

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (oC)	Redd Area (m^2)	Egg Depth (cm)	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
California	S:--- E:mid-Jan P:---	---	3.13	38	-small cobble 7.5-15.0 cm with large gravel 5.0- 7.5 cm -gravel embeddedness of 0-10%	0.31- 0.61	0.42	-evaluated use of artificial spawning riffles by chinook and coho salmon below the Lewiston dam on the Trinity River -characterized spawning habitat, developed utilization curves and evaluated the effectiveness of boulder clusters as cover for spawners	28
Pacific Southwest	S:--- E:--- P:Nov- Jan	Range; 6- 12°C	1.7- 5.2	18- 38	-particle sizes from 1.3- 15.0 cm in diameter	0.1- 0.54	18- 76	- describes life history and environmental requirements of coho salmon in the Pacific southwest - spawn in lower end of pools just above riffles	109

CHINOOK SALMON

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (°C)	Redd Area (m^2)	Egg Depth (cm)	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
Columbia River	Spring Run: S:Aug 20 E:Sep 15 P:Aug 28- Aug31 Summer Run: S:Sep 7 E:Nov 15 P:Sep 20 Fall Run: S:Sep 20 E:Nov 2 P:Sep 30	Range: 4°C - 17°C	Avg: 2.44-6.55	Avg: 21.3-26.8 Range: 5.0- 50.0	-6- 41% >15.0 cm -59- 95% ≤15.0 cm -3- 8% mud, sand and silt	Avg: 0.21- 0.27 Range: 0.05- 1.20	---	- determines stream area required by spawning Pacific salmon pairs in Columbia R. tributaries - preference for moderately bound streambed materials rather than free-rolling gravel or firmly bound rubble and areas with good intragravel water flow - values cited represent combined measurements of spring, summer and fall runs of chinook salmon	31
Oregon	---	---	---	---	---	0.18- 0.24 (minimum)	21- 76	- range of values indicated combines criteria recommended by Smith for spring and fall chinook salmon	258
Idaho	---	---	---	---	- most spawning in sediments with a geometric mean particle size of 7.0 to 20 mm	---	---	- study reports on substrate particle size mixtures used by chinook for spawning and describes the geometric mean paticle diameter method for analyzing and evaluating spawning sediments - area of study concentrated in the Salmon River drainage, including its two major tributaries, the South Fork and Middle Fork Salmon Rivers - watershed characterized by a predominance of bedrock, steep slopes and erosion-prone soils	219
Western USA	---	Range: 5.6- 13.9°C	3.3- 5.1	---	-particle sizes of 1.3- 10.2 cm	0.12- 1.22	0.08- 109	- values shown do not differentiate between spring, summer or fall spawning runs of chinook salmon	232

CHINOOK SALMON

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (oC)	Redd Area (m^2)	Egg Depth (cm)	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
Lower Michigan	---	---	---	---	---	---	>30	- surveyed 60 streams in lower Michigan for natural reproduction of chinook and coho salmon - chinook salmon tended to prefer main stream spawning habitat with stream widths > 5 m	37
British Columbia	S:--- E:--- P:Sep 7- Sep 25	---	Mean: 9.1- 10.0 Range: 0.5- 27.5	---	Fredle index: Mean: 5.4- 6.0 Range: 0.6- 22.8	Mean: 0.85- 0.88 Range: 0.46- 1.20	Mean: 55- 56 Range: 15- 100 (15cm above substrate)	- describes spatial distribution of chinook salmon redds and redd characteristics with respect to length of redd occupancy and start of redd construction - spawning observed approx. 7 and 9.5 km downstream from the head of the Nechako River, B.C. - preference for spawning along lateral gravel ridges	194
Lake Superior Tributaries	early May	---	---	---	---	---	---	- documents first reported spring spawning by Chinook salmon in the Michipicoten R.	157
Columbia River	S:Oct 10 E:3rd wk Nov P:2nd wk Nov	---	Mean: 17 Range: 2.1- 44.8	Mean: 19 Range: 10- 33	4.3- 5.8%- $\leq$0.85 mm 7.3-9.7%- $\leq$2.0 mm 14.5-19.2%- $\leq$6.0mm 23.7-36.2%- $\leq$19.1mm 64.7-67.7%- $\leq$76.2mm	---	> 100 (20 to 25 cm above substrate)	- determined effects of different minimum flows caused by hydropower operations on spawning and egg survival of chinook salmon at Vernita gravel Bar in the Columbia River - 2oo m wide Vernita Bar located approx. 5 km downstream from Priest Rapids dam - Chinook redds distributed in long narrow band parallel to bar and extending 5 km	46

CHINOOK SALMON

Where	Spawning Period Start/ End / Peak (S / E / P)	Spawning Temperature (oC)	Redd Area (m^2)	Egg Depth (cm)	Substrate	Water Depth (m)	Current Velocity (cm/s)	Comments	Source
California	S:3rd wk Sept E:3rd wk Nov P:---	---	4.82	42	-small cobble 7.5-15.0 cm with large gravel 5.0- 7.5 cm -gravel embeddedness of 0-10%	0.31- 0.61	45	-evaluated use of artificial spawning riffles by chinook and coho salmon below the Lewiston dam on the Trinity River -characterized spawning habitat, developed utilization curves and evaluated the effectiveness of boulder clusters as cover for spawners	28
Lake Huron	---	---	---	---	- large boulders and loose gravel $\leq$ 8 cm dia.	1.3	---	- documents occurrence of shoal spawning by chinook in Iroquois Bay, Lake Huron, over traditional lake trout spawning shoals	222

PINK SALMON

Where	Spawning Period Start/ End /Peak (S / E / P)	Spawning Temperature (oC)	Redd Area (m^2)	Egg Depth (cm)	Substrate	Water Depth (m)	Current Velocity (cm/s)		Comments	Source
Western USA	---	7.2- 12.8°C	0.6- 0.9	---	-particle sizes from 1.3- 10.2 cm	0.15- 0.53	21- 101 (12 cm above streambed)	- details requiremer salmon	habitat ts of anadromas	232
North Shore Lake Superior	S:Sep 6 E:--- P:Oct.2- 3	11- 13°C	0.40-0.96	---	- maximum particle size <5 cm	0.22- 1.10	4.6- 15.5	- describe pink salmo Superior a expansion Great Lake - some det are presen salmon in Michipicot tributarie - redds co upstream e	s introduction of n into Lake nd their throughout the s ails of spawning ted on pink the Steel R. and en R. two s of L. Superior ncentrated at nds of riffles	155
North Shore Lake Superior	S:Sep 1 E:Sep 30 P:Sep 10	At peak spawning: 10- 17°C	---	---	---	---	---	- describe migration north shor Superior - study ar Pancake Ri characteri cross-sect relatively near their outwashes steep falls - short spa located wit mouth	s inshore of pink salmon on s of Lake ea in Carp and vers ed by small ional areas short flat zones mouths, sandy into the lake and farther inland awning areas are hin 10 km of	156

APPENDIX 2

SUMMARY OF REHABILITATION ALTERNATIVES FOR RESTORING SPAWNING HABITAT OF WALLEYE AND SALMONIDS IN STREAMS

SUBSTRATE ADDITION

Objectives	Study Area	Methods Implemented	Results	Source	Problems/Comments
-to investigate spawning site selection by walleye and spawning success on several bottom types	-a series of lakes comprising most of a Mississippi R. headwater reservoir -one known lakeshore spawning site composed of firm sand substrate chosen for enhancement	-deposition of substrate Area: 90 m^2 SUBSTRATE DEPTH: 15.0 cm SUBSTRATE DESCRIPTION: pit-run gravel screenings SUBSTRATE SIZE: 2.5- 15.0 cm	-egg abundance 10 times greater 2 years after enhancement -egg survival 5 times greater -fry production increased more than 100 times	135	Instability of introduced substrates is often cited as a factor limiting the success of artificial salmonid spawning beds in streams, since deposited gravel tends to be carried downstream by high flows unless stabilized (Anon. 1980, Reeves & Roelofs 1982, White and Brynildson 1967). Repeated introductions may be required to replace gravel that has been transported away from the site (Reeves & Roelofs 1982). Choice of sites with relatively stable flows and inclusion of some fine sediments in introduced gravel have been recommended to improve stability. Poor site selection may result in siltation of spawning beds at either stream or lake sites (White & Brynildson 1967, Newburg 1975).
- to improve spawning area for brook trout	- 4 Adirondack Lakes, New York with predominantly sandy bottoms or sand overlaying gravel with areas of spring seepage - rehabilitation sites located at or near natural brook trout spawning areas in or proximal to tributaries associated with the Lakes	UPWELLING SPAWNING FACILITIES: - spawning facilities consisting of 2.4 X 2.4 X 0.25 m gravel-filled boxes constructed in 2 lakes - upwelling simulated by piping water from a nearby tributary through perforated pipes buried in the gravel - boxes submerged in 0.3 to 1.05 m of water SUBSTRATE ADDITION: - substrate excavated and replaced with gravel at a number of other sites AREA: 7.5 X 0.9 m SUBSTRATE DEPTH: 10- 15 cm SUBSTRATE DESCRIPTION: washed gravel SUBSTRATE SIZE: 75-90% - 2.5 cm 10-25% - 1.3 cm	UPWELLING SPAWNING FACILITIES: - 3 of 4 boxes installed on or near known spawning grounds were used extensively by brook trout and the fourth has had limited use - spawning facilities located on sites with no previous spawning history were not employed - failure of these sites may have been caused by the thermal conditions of the piped in water which would not have been characteristic of upwelling groundwater SUBSTRATE ADDITION: - utilization of introduced substrate in streams where spawning had occurred previously but none where there was no recent spawning history - no utilization of improved lake sites at or near known spawning areas	292	
- to improve walleye spawning grounds in lakes that lack good habitat	- Minnesota lakes	- substrate "golf ball to baseball size" added to shallow areas in lakes.	- article reports generally on management of walleye fishery in Minnesota.	273	

SUBSTRATE ADDITION

Objectives	Study Area	Methods Implemented	Results	Source	Problems/Comments
- to determine the effects of walleye spawning site enhancement on egg deposition and survival.	-enhancement site consisted of a natural walleye spawning ground located below Bobcaygeon dam on that section of the Otonabee River separating Sturgeon and Pigeon Lakes in the Kawartha Lakes, Ontario. - area below the dam composed of large blocks of limestone separated by crevices up to 30 cm wide with deposits of rock particles at the bottom of these crevices.	- experimental gravel beds constructed by depositing substrate in retaining structures located on limestone bedrock in the area of most concentrated walleye spawning activity - during 2nd year of study, retaining structure built with concrete blocks replaced with concrete curbs after partial destruction of original structure. Blocks / Curbs AREA: (3) 3 X 3 m / 12 X 9 m DEPTH: 20 cm / 15 cm SUBST.SIZE: 5- 15 cm / 5- 25 cm	- egg deposition greater on treatment areas in both years. - egg survival considerably lower on concrete block structure than on control areas but egg survival the next year on the curb structure exceeded that of control sites.	7	
- to restore or create salmonid spawning habitat degraded through heavy sedimentation.	- Perkins Creek, a small intermittent tributary in Puget Sound, Washington. - study area characterized by patches of shallow gravel 5-10 cm deep overlying clay or dirt.	- study area dredged and streambed replaced with gravel. - wooden weirs installed to create optimal stream gradient for chum salmon. AREA: 180 m long SUBSTRATE DEPTH: > 22.5 cm SUBSTRATE DESCRIPTION: - commercially processed gravel - use of pit-run gravel rejected due to high proportion of sand and dirt SUBSTRATE SIZE: 1.0 to 5.0 cm	- spawner utilization 6 to 7 times higher at improved area than at unimproved site. - egg-to-fry survival 3 times greater at rehabilitated site than at control areas. - some shifting of gravel noted - accumulation of fines at wooden weirs which may be prevented by drilling holes to allow silt to pass downstream.	91	
- to provide new spawning areas for walleye to replace deteriorated habitat.	- Lake Nipissing shoreline.	- 2 triangular reefs constructed adjacent to shoreline by addition of substrate. AREA: 21 X 21 X 15 m 9 X 9 X 6 m SUBSTRATE DEPTH: 75- 90 cm SUBSTRATE DESCRIPTION: large reef - angular broken rock. small reef - pit run gravel SUBSTRATE SIZE: large reef - "rock chips" to 40 cm dia. small reef: 2.5 to 20.0 cm	- not reported.	106	

SUBSTRATE ADDITION

Objectives	Study Area	Methods Implemented	Results	Source	Problems/Comments
- to improve natural recruitment of walleye through provision of suitable spawning substrate.	- Jennie Weber lake, northeastern Wisconsin, a 241 acre lake with a max. depth of 2.4m and a median depth of 0.9m. - shoreline bottom types primarily sand and muck.	- substrate deposited at three sites along lakeshore. AREA: 3 m dia. circle 30 X 48 m rectangle DEPTH: 15.0 cm SUBSTRATE DESCRIPTION: washed field rock SUBSTRATE SIZE: 2.5 - 25 cm (avg. 10 cm)	- 2 of 3 reefs used by spawning walleye with occurrence of advanced egg development. - not successful in establishing year classes. - substrate depth of 30 cm subsequently recommended to compensate for silting and settling.	180	
- to develop criteria for the design and placement of artificial spawning shoals for walleye management.	- Lake Osakis, Minnesota, a 2508 ha lake with a max. depth of 20.1m and a shoreline perimeter of 84.8 km. - rehab. site consisted of a 2.4m wide marginal spawning shoal located along the lakeshore and presently used by walleye.	- 2 overlapping shoals developed by placement of substrate over natural gravel along shore. AREA: 85.5 X 15 m (area No.1) 75 X 18 m (Area No. 2) SUBSTRATE DEPTH: 30 cm SUBSTRATE DESCRIPTION: large rubble SUBSTRATE SIZE: Area 1 - 5-17.5 cm (avg. 10 cm) Area 2 - 10% 27.5 - 50 cm 80% 17.5-27.5 cm 10% < 17.5 cm	- egg deposition and survival greatest on deep water natural shoal, intermediate on shoal No. 2 and lowest on shoal No. 1. - fry contribution from artificial spawning shoals estimated at 15% - concluded that costs of spawning site rehabilitation exceeded those of stocking fry. - recommendations for design and placement of artificial spawning shoals included: placement on firm substrate to minimize sinking or site stabilization with a 15 cm foundation layer of 1.3-2.5 cm rock, and a spawning substrate mixture of 10% - 7.5 - 12.5 cm 50% - 12.5- 17.5 cm 40% - 17.5 - 22.5 cm	195	
- to test for substrate selection by spawning walleye in streams; to examine effects of substrate and flow on egg survival; and to determine holding areas of adults and migratory fry behaviour.	- intermittent tributary of Falcon Lake, Manitoba. - stream characterized by riffles and pools at upstream end and deep, slow pools at meandering downstream section. - stream width 2.0 m to 6.0 m, averaging 4.2 m - spawning mainly in upstream section below a small waterfall in areas of natural gravel and cobble deposits.	- 4 gravel beds constructed in area of sand substrate in downstream section by addition of gravel and rubble SITE AREA: 6m X 3.6m SUBSTRATE DEPTH: 60 cm SUBSTRATE DESCRIPTION: gravel and rubble from gravel pit. SUBSTRATE SIZE: -> 50% over 0.6 cm dia. -approx. 30% sand -some stones > 7.5 cm also included.	- all beds were used by spawning walleye with occurence of greater egg deposition at 2 downstream sites. - egg survival on experimental beds greater than on adjoining sandy areas (37% vs 3.4%) - utilization of beds by white suckers also observed.	93	
- to maintain natural reproduction of walleye through rehabilitation or enhancement of spawning habitat	---	- extension or improvement of sites presently used by spawning walleye by addition of substrate SUBSTRATE DESCRIPTION: - cobble from gravel pits, farmer fencerows, etc. SUBSTRATE SIZE: 7.5 - 25 cm	- no results reported - article briefly summarizes strategies to consider for walleye spawning bed rehabilitation.	169	

SUBSTRATE ADDITION

Objectives	Study Area	Methods Implemented	Results	Source	Problems/Comments
- to increase the area of suitable and accessible walleye spawning substrate, thereby increasing walleye production and improving angling opportunities.	- Bar River near Sault Ste. Marie, Ontario, downstream of a natural walleye spawning riffle whose access by walleye is limited during years of low spring flows. - stream width approx. 9 m with clay substrate at rehab. site.	- substrate deposited across the entire channel width from a depth of approx. 30 cm at upstream extent to 10 cm at downstream extent in order to create the desired hydraulic conditions for spawning by walleye. AREA: 9 m X 28.6 m SUBSTRATE DEPTH: 10- 30 cm SUBSTRATE DESCRIPTION: broken angular rock geologically similar to rock presently in the Bar River rapids. SUBSTRATE SIZE: 2 cm- 30 cm - large boulders also placed to create cover.	- no use of artificial spawning bed observed the first spring after rehabilitation, however, traditional spawning area at rapids accessible due to sufficient flows (Andre Dupont, pers. comm.)	OMNR-unpubl.	

SUBSTRATE STABILIZATION AND RECRUITMENT

Objectives	Study Area	Methods Implemented	Results	Source	Problems/Comments
- to investigate the use of streambed control devices in the minimization of gravel erosion in salmonid spawning tributaries	- Jorsted Creek in the Puget Sound area, Washington. - characterized as a small stream where chum salmon production is severely limited by gravel washout	installed a series of two-tiered gabion weirs across the streambed and perpendicular to the flow - notch constructed near the center of the weir to permit fish passage during low flows. - streambank stabilized with placement of riprap rock along the ends of weirs	- improper installation initially caused functional and structural integrity of weirs to fail - subsequent modifications resulted in creation of a series of short spawning channels	91	GABIONS - gabions have the potential to create favourable upstream hydraulic conditions for salmonid egg incubation that is comparable or superior to that of natural riffles (Anon. 1980) - improper installation may result in failure of the structure to recruit or stabilize substrates, dislodgement or destruction during high flows, or creation of a barrier to fish passage during low flows (Reeves and Roelofs 1982) -restriction of gabion installation to stable, straight, low-gradient stream sections recommended (Kouse & Boehne 1985, Klassen & Northcote 1988, Reeves & Roelofs 1982)
-to evaluate the use of gabion weirs for the enhancement of salmonid spawning habitat through recruitment and stabilization of gravel	- a steep, rapid run-off stream damaged by landslides caused by heavy logging in the Queen Charlotte Islands, British Columbia. - Sachs Creek subject to rapid increases in flow up to 65 m^3/s with a summer low flow of 0.1 m^3/s	- tandem, V-shaped gabions weirs installed at 2 low gradient sites (1- 2% slope) and 1 high gradient site (3% slope). - weirs stabilized by embedding gabions in 1m trenches excavated in the streambed and streambank. - riprap placed to minimize erosion. - pit-run gravel from 0.2 to 6.0 cm spread over the sites to provide suitable salmonid spawning substrate	- development of plunge pools and gravel bars at all sites within the first year. - stabilization of streambed in 1.5 years at low-gradient sites. - continued gravel scour at high gradient sites threatening site integrity and weir function (Klassen & Northcote 1986). - use of gabion sites by spawning salmonids. - improvement in intra-gravel environment (D.O., permeability and composition). - creation of juvenile salmonid rearing habitat (Klassen & Northcote 1988, Klassen 1988)	146, 147, 148	

SUBSTRATE STABILIZATION AND RECRUITMENT

Objectives	Study Area	Methods Implemented	Results	Source	Problems/Comments
- to determine the stability of stream enhancement structures and their effects on stream characteristics and salmonid populations	- 1.5 km upstream from the mouth of East Fork Lobster Creek, a tributary of the Alsea River watershed in Oregon. - average annual flow is 1.2 m^3/s with a peak winter flow of 38.5 m^3/s. - limited pool habitat with riffles composed primarily of cobble/rubble and a poverty of salmonid spawning gravel	- V-shaped gabion weirs installed in series at 7 sites with gradients <3%. - gabions anchored by steel bars driven through the weirs into the streambed, by securing a cable threaded lengthwise through the structures to the streambank and by embedding gabion wings 1- 5 m into the banks. - riprap applied on streambank to prevent erosion. - boulder clusters placed in riffle and bedrock areas. - log sills installed at 3 sites by inserting one end into the streambank and securing the other end in the channel with clusters of boulders	- formation of pools and gravel bars, improved gravel quality, increased pool:riffle ratio and improved rearing habitat at gabion sites. - spawner use of gabion gravels higher than that of naturally deposited gravel at untreated sites. - rapid stabilization of streambed at gabions at 3% slope but continual scouring and deposition at lower gradient sites. - log sills initially effective at accumulating gravel, but two of the structures floated during high flows causing loss of deposited materials and downcutting under the logs. - boulder clusters reduced exposed bedrock 52% and increased gravel 27%	124	LOG AND ROCK SILLS - the Hewitt ramp (a log sill dam formed by a cross-channel log supported with posts angled into the streambed on the upstream side of the log) has been recommended by White and Brynildson (1967) for creating pools in high gradient streams. - Reeves and Roelofs (1982) and Hall and Baker (1982) report on successful implementation of this structure for recruitment and stabilization of salmonid spawning gravel. - cedar board dams, consisting of a cross channel log with two other logs forming a V pointing downstream and lined with wooden shingles, have been recommended for accumulating gravel in small, stable streams (Hall and Field - Dodgson 1981, Reeves and Roelofs 1982)
-to increase and improve spawning habitat for rainbow trout	-East Side Channel of the Missouri River below the Fort Peck dam -side-channel approx. 4 km long with a sand/silt bittom at the upstream end, progressing to gravel and cobble downstream -traditional rainbow trout spawning and rearing habitat located in the channel -rehabilitation area charactized by hydraulic conditions typical of rainbow trout spawning areas	-2 boulder dikes, approx. 45 m long and 0.60- 0.90 m high were built in the channel diagonal to the flow -washed and graded gravel from 1.9- 6.25 cm diameter were deposited between the dikes and allowed to be distributed by the current -boulders were placed between the dikes to provide cover for spawning trout	-effectiveness of rehabilitation was not assessed at the time of the report	88	

SUBSTRATE STABILIZATION AND RECRUITMENT

Objectives	Study Area	Methods Implemented	Results	Source	Problems/Comments
- to increase available chinook spawning habitat	- Fish Creek, a fifth order tributary of the Clackamas R. in Oregon. - wide seasonal flow fluctuations ranging from an average of 0.5 m^3/s at the mouth and annual high flows of >100 m^3/s - limited spring chinook spawning habitat present	- installation of 18 cross channel and 3 half channel boulder berms for deposition of stream bedload transported by the current. - large boulders in vicinity of berm site repositioned to form downstream pointing V with total lengths of 20- 30 cm and a height of 0.6 to 0.8 m above the streambed. - sites with straight, low gradient (<2%) channels or tail out area of relatively large bedrock controlled pools chosen for enhancement to optimize structural stability and longevity	- projected increase of 200 to 300 m^2 of gravel suitable for chinook spawning	114	

GRAVEL CLEANING

Objectives	Study Area	Methods Implemented	Results	Source	Problems/Comments
-to evaluate the effects of the "riffle sifter" on the bottom fauna of anadromous salmonid spawning gravel	-3 streams in southeast Alaska	-streambed gravel cleaned by "riffle-sifter" and benthic abundance evaluated before and after treatment -"riffle sifter" uses high-velocity water jets mounted on a self-powered, amphibious vehicle to flush silt from gravel -silt-laden water is then sprayed onto the streambank	-variable success in removal of fines <0.4 mm, ranging from decreases of 30% to 65% -initial reduction of bottom fauna with subsequent recolonization to pre-treatment levels within 1 year	184	RIFFLE-SIFTER -plagued with mechanical problems and eventually abandoned -modified machine developed by Mih still being field tested as of 1982 (Hall and Baker 1982)
-to develop a machine for cleaning spawning gravel of anadromous salmonids	-machine tested in laboratory flumes and 3 streams in Idaho and Washington -water depths in streams from 18 to 91 cm	-attempted to modify the "riffle-sifter" by experimenting with placement and size of jets -laboratory and field tests conducted	-decrease of 20 to 40% silt in substrates, with an average cleaned depth of 15 to 30 cm, when field tested in the streams -persistence of some mechanical difficulties	186	
-to design a method for cleaning salmonid spawning gravel in an artificial spawning channel	-conducted tests of gravel-cleaning methods in laboratory flumes that simulated conditions in the Tehama-Colusa Canal, Sacramento R., California, which functions as both an irrigation and spawning channel -canal characterized by a width of 30 m, a water depth of 0.45 m and spawning gravel from 1.9 to 15.0 cm placed to a depth of 60 cm	-baffle-gate method determined to be most practical procedure for cleaning the gravel in the canal -to clean gravel, the baffle-gate, consisting of a piece of plywood mounted vertically on a movable carriage, is lowered into the flowing water, producing increased water velocity below the gate sufficient to scour gravel and flush fines from the substrate -baffle-gate is moved upstream as cleaning progresses	-in laboratory tests, the baffle-gate was effective at efficiently flushing sediments from the canal substrate -shifted gravel was relaid after cleaning	41	BAFFLE-GATE -Mih (1978) suggests that this method is unsuitable for irregular natural streams because of the size of the equipment and the forces required to hold the gate in position
-to develop a practical method of cleaning sedimented salmonid spawning gravel in streams	-4 streams used by anadromous Pacific salmon for spawning in Puget Sound tributaries, Washington	-streambed gravel manipulated with a caterpillar-type bulldozer to dislodge fines which are then washed downstream by the current	-decrease in quantity of fines <0.841 mm in diameter from 17.7% before cleaning to 12.8% or less up to two years from date of rehabilitation -utilization of cleaned areas by spawners -greater pre-emergent fry survival in cleaned than in uncleaned areas	91	BULLDOZER -potential detrimental effects on rearing areas, food organisms, riffle stability and downstream spawning areas (Anon. 1980, Mih 1978) -generally, this method is limited to larger streams (Reeves and Roelofs 1982) -effectiveness of gravel cleaning is likely to depend on stream flow velocity (Mih 1978)

GRAVEL CLEANING

Objectives	Study Area	Methods Implemented	Results	Source	Problems/Comments
-to increase living space for brook trout and to enhance or restore the sport fishery	-Wisconsin spring ponds, usually situated at headwaters of trout streams in remote locations -pond area from 0.36 to 2.51 ha with mean and maximum depths from 0.64 to 1.68 m and 1.68 to 5.18 m, respectively	-shoreline of ponds hydraulically dredged to remove organic soils from underlying gravel substrate -remaining sediments flushed from the site	-use of 2 of 3 rehabilitated sites by spawning brook trout and increased juvenile recruitment in ponds after dredging (Carline 1980) -increase in spawning area available to brook trout and increase in number of redds at developed sites (Carline and Brynildson 1977)	38, 39	HYDRAULIC DREDGING -this method may not be economically sound in all situations -periodic maintenance may be required to remove continual accumulation of organic materials (Carline and Brynildson 1977)
-to evaluate the effects of stream alteration methods on brook trout survival and stream carrying capacity	-study area consisted of a 3.2 km section on the west branch of the Split Rock River, a tributary of Lake Superior -stream gradient of 0.37 m/30.5 m with low and high flows of 0.034 m^3/s and 1.416 m^3/s, respectively -absence of pools and shelters -substrate composed of rubble and boulder with some silt and gravel	-wing deflectors placed in streams to create current conditions that would scour silt and sand from gravel	-change in streambed composition from 26% silt and 14% gravel to 17% silt and 24% gravel after alteration	99	WING DEFLECTORS -wing deflectors recommended by White and Brynildson (1967) as a less disruptive method of improving trout spawning habitat than construction of artificial spawning beds -Hubbs et. al. (1932) reported that wing deflectors in some Michigan streams (6 to 18 m stream width) exposed from 4.5 to 108 m^2 of bed gravels, portions of which were subsequently used by rainbow trout as spawning habitat
-to increase suitable spawning habitat for rainbow trout by loosening and cleaning stream gravel	-East Side Channel of the Missouri River below the Fort Peck dam -side-channel approx. 4 km long with a sand/silt bottom at the upstream end, progressing to gravel and cobble downstream -traditional rainbow trout spawning and rearing habitat located in the channel -rehabilitation area charactized by hydraulic conditions typical of rainbow trout spawning areas	-gas-powered water pump, fire hose and high pressure nozzle used to loosen and flush fines from gravel in 2 riffle areas	-no spawning by rainbow trout occurred at the cleaned areas, however this may have been a consequence of higher than normal spring discharges during the year of evaluation	88	FIRE HOSE -Reeves and Roelofs (1982) note that sufficient flow is necessary to transport dislodged silt from the area -the Stream Enhancement Guide (Anon. 1980) recommends this method in preference to the use of heavy equipment since there is less risk of disturbing or degrading spawning areas -Macins (1981) recommends this method for cleaning walleye spawning substrates

GRAVEL CLEANING

Objectives	Study Area	Methods Implemented	Results	Source	Problems/Comments
-to describe a semi-natural rearing channel for production of coho salmon smolts	-excavated channel alongside the Big Qualicum River, B.C., with constructed series of riffles and pools and controlled flow -gravel sizes of 1.3 to 3.8 cm and 30 cm depth -discharge approx. 0.4 m^3/s	-channel cleaned with a fire hose to remove sand, algae and fish feces	-recolonization of substrate by benthos 3 weeks after cleaning	190	

ARTIFICIAL SPAWNING CHANNELS

Objectives	Study Area	Methods Implemented	Results	Source	Problems/Comments
- to develop new salmonid spawning areas and upgrade existing spawning areas in groundwater-fed side channel	- sites appropriate for side channel development projects include medium to large size rivers with porous bench gravel and adequate groundwater near the surface - sufficient gradient to create required hydraulic conditions, protection from flooding and natural spawning grounds nearby are also required	- existing channel graded down to intercept a greater portion of the subsurface groundwater - channel lengthened and widened to increase spawning area - natural gravel cleaned or other substrate introduced - installation of weirs to control channel gradient and channel armoring may be required	- approx. 42000 m^2 of new and improved spawning habitat created at 11 project sites in British Columbia rivers - avg. benefit/cost of 1.7:1, ranging from 0.3:1 to 2.4:1 (Marshall 1986) -in an assessment of chum egg-to-fry survival at 7 improved groundwater-fed spawning areas, survival varied from 1.0 to 34.3% (Lister et. al. 1980)	174, 163	
-to mitigate the loss of kokanee salmon spawning habitat resulting from dam construction	- spawning channel constructed next to Meadow Creek, a tributary of the Columbia River system in British Columbia, and a traditional Kokanee spawning area	- 3.36 km long sinuous channel dredged, with a base width of 10.5 m and a depth of 1.8 m - clean graded gravel (0.015 to 6.25 cm) deposited to a depth of 23 cm - cover and gravel stabilization provided with cross-channel log structures - natural appearance of stream maintained - flow regulating devices installed	- channel used extensively by spawning kokanee - survival rate consistently as high as 40% - channel requires occasional cleaning of gravel to remove accummulated silt	188	
- to increase angling opportunities through the construction of an artificial walleye spawning channel	- a tributary to the Upper Rideau Lake beside a hatchery proposed for channel construction	- proposed design of the channel specified a minimum spawning area of 135 m^2, a gravel substrate from 5.0 to 25.0 cm at least 15 cm in depth, and provisions for controlling hydraulic conditions in the channel	- report documents design criteria for a proposed artificial walleye spawning and incubation channel	228	

SPAWNING MARSHES

Objectives	Study Area	Methods Implemented	Results	Source	Problems/Comments
- to assess fingerling production in marshes managed for spawning and rearing of northern pike	- 2 managed Wisconsin marshes adjacent to lakes - area ranges from 1.48 ha to 7.4 ha - Pleasant L. Marsh predominated by a central leatherleaf mat - Pabst Marsh characterized by reed canary grass	- marshes created by flooding low-lying areas adjacent to lakes - water controlled by dams at the outlets of the marshes - water depth of 0.6 to 1.2 m maintained throughout the spawning and rearing period by pumps - spawning stock of northern pike released into the marshes for spawning and subsequently removed after spawning was completed - fingerlings were collected by a wire mesh pen placed in front of the dam during marsh drainage with pumps	- average stocking rate of 13.5 kg/ha (ratio of 3.2 males:1 female) produced an overall average of 1332 fingerlings/acre with a mean length of 89 mm by the beginning of June - recommended marsh characteristics include that it be completely drainable, close to a water supply, predominated by sedges and grasses, and predator-proof - significant fingerling mortality experienced when marsh drainage was conducted at temperatures near 26.7°C	81	